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Hijiya et al.

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[54] FLUID BEARING

[75] Inventors: Toshinori Hijiya; Katumi Saitou, both of Tokyo, Japan

[73] Assignee: Copal Company Limited, Tokyo, Japan

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[58] Field of Search 310/90.5, 156, 44, 154, 310/254, 157, 90; 384/114, 115, 107, 279, 902, 113, 121

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Primary Examiner—R. Skudy
Attorney, Agent, or Firm—Finnegan, Henderson, Farabow, Garrett & Dunner

[57] ABSTRACT

A dynamic pressure-type fluid bearing usable in a polygon mirror scanner for a laser beam printer includes a sleeve having an inner peripheral surface and a bottom face, and a journal having an outer peripheral surface cooperating with the inner peripheral surface of the sleeve across a predetermined clearance, and an end face cooperating with the bottom face of the sleeve. In an embodiment, the sleeve is rotatable relative to the journal and is held by a magnetic retaining force in such a manner that a predetermined gap is formed between the bottom face of the sleeve and the end face of the journal even when the bearing is at rest. The bottom face of the sleeve includes a porous body so that the gap between the bottom face and end is communicated with the outside of the bearing.

15 Claims, 7 Drawing Sheets

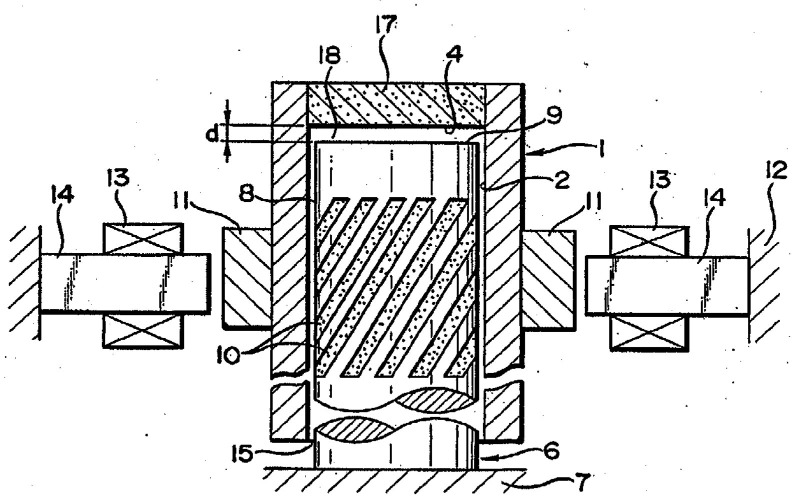

FIG. 5 shows a fifth embodiment of the present invention, in which the sleeve 1 is stationary, the journal 6 is rotatable, and the journal 6 is caused to float, even when at rest, by the magnetic attracting force. When the journal 6 is rotated, the gas drawn into the gap 18 is slowly discharged from a porous body 17C fixedly secured in the end portion of the sleeve 1 via a support member 22. As a result, the interior of the gap 18 is held at a constant pressure. The effects of this embodiment are the same as those of the first embodiment.

FIG. 6 shows a sixth embodiment of the present invention, in which the sleeve 1 is stationary, the journal 6 is rotatable, and the journal 6 is caused to float, even when at rest, by the magnetic attracting force, thereby forming the gap 18. The effects of this embodiment are the same as those of the first embodiment.

FIG. 11 illustrates an example in which the above-described fluid bearing is applied to a laser scanner. As shown in FIG. 11, a housing 112 comprises a cylinder which is open at its upper end and closed at its lower end. The lower end of housing 112 is machined to have a step portion after the housing is subjected to drilling work. A journal 106 provided with grooves 110 for producing dynamic pressure is inserted into the housing 112, after which the journal is arranged to depend from the lower face of the housing.

An electromagnet assembly 130 is provided at a prescribed location in the lower portion of the housing 112 and is electrically connected to a selective energizing circuit 115. The electromagnet assembly 130 includes a total of 18 circumferentially arranged small electromagnet assemblies or stators each constructed in such a manner that a coil 113 is inserted into a respective yoke 114. A revolving magnetic field is produced in the electromagnet assembly 130 when the small electromagnet assemblies are energized by the selective energizing circuit 115.

The housing 112 is provided with a glass window 126 for input and output of a laser beam. A laser beam after being reflected by a polygon mirror 103, described below, is outputted upon passing through the glass window 126.

A sleeve 101 comprises a cylinder having an inner diameter several microns larger than the outer diameter of the journal 106 and is provided at its upper portion with a flange 102 on which the polygon mirror 103 is mounted. A total of six permanent magnets 111 are provided on the lower portion of the sleeve 101 circumferentially thereof. These magnets are fixed at prescribed positions by a ring 104. The outer diameter of the ring 104 is less than the diameter of an inner circumferential surface formed by the 18 stators 114 of the electromagnet assembly 130. A porous body 117 is fixedly secured to the upper portion of the sleeve 101.

The sleeve 101 thus assembled is fitted over the journal 106. The permanent magnets 111 of the sleeve 101 are attracted to the stators 114 so that the bottom face of the porous body 117 will not contact the upper end face of the journal 106. As a result, a prescribed gap is maintained between the bottom face of the porous body 117 and the upper end face of the journal 106.

Finally, a cover 120 is attached to the upper end of housing 112 by screws. An axial securing body 121 is provided on the central portion of the cover 120. When the sleeve 101 is urged thereby, the latter will not be damaged if subjected to impact during transport. The arrangement is such that the axial securing body 121 is made to free the sleeve 101 when the apparatus is used.

The present invention can be modified in various ways without departing from the scope of the claims. For example, the grooves for producing dynamic pressure can be provided on the radial inner peripheral surface of the sleeve 101 rather than on the journal.

Some advantages which stem from use of a fluid bearing according to the present invention are as follows:

(1) A predetermined gap of e.g. 0.5–3.0 mm is formed between the thrust bottom face and thrust end face even when the bearing is at rest. As a result, the thrust bottom face and thrust end face do not sustain friction-induced damage when the bearing is started and stopped.

(2) A gas swept into the gap between the thrust bottom face and thrust end face through the radial inner peripheral surface and radial outer peripheral surface at rotation is slowly discharged through the porous material. Owing to the internal pressure self-regulation action produced by the orifice effect of the porous body, stable high-speed rotation without vertical fluctuation is assured.

(3) A gas swept into the gap between the thrust bottom face and thrust end face becomes a compressed gas layer the thickness of which is several orders of magnitude larger than the small clearance in the radial direction. The presence of this gas layer and the fact that the gas is slowly discharged by the porous body serve to suppress up-and-down vibration of the rotational system when an impact is received.

(4) The sleeve or the journal, whichever is rotatable, is held by a magnetic retaining force in such a manner that a predetermined gap is formed between the thrust bottom face and thrust end face even when the bearing is at rest. When the predetermined gap is brought into gradual communication with the outside by the porous body, the pressure in the gap between the thrust bottom face and the thrust end face is held constant at all times by the porous body during high-speed rotation of the rotational system. As a result, stable, high-speed rotation of the rotational system without vertical fluctuation is assured.

(5) If a predetermined gap of e.g. 1.0–1.5 mm, in a case where the diameter of the journal is 16 mm, is formed between the thrust bottom face and thrust end face even when the bearing is at rest, the thrust bottom face and thrust end face will not contact each other when a gas inside the predetermined gap flows into the small clearance of several microns between the radial inner and outer peripheral surfaces at the start of bearing operation. As a result, there is absolutely no danger of friction-induced damage when the bearing is started and stopped.

(6) The porous body can be readily formed by sintering powder material, which can be regarded as an assemblage of a multiplicity of capillary tubes. The gas permeability of the porous body can be freely controlled by regulating the particle diameter of the sintered metal particles, the thickness of the element and the area thereof.

What is claimed is:

1. A fluid bearing comprising:

a sleeve having a radial inner peripheral surface and an end portion with a thrust bottom face; and

a journal having a radial outer peripheral surface opposing said radial inner peripheral surface of the sleeve, and an end portion with a thrust end face opposing said thrust bottom face;

one of said sleeve and said journal being mounted to rotate relative to the other with a predetermined clearance between said radial outer peripheral surface and said inner peripheral surface;

a magnetic retaining force means for magnetically supporting said rotatable one of the sleeve and the journal forming a predetermined gap between said thrust bottom face of the sleeve and said thrust end face of the journal;

said end portion of one of the sleeve and the journal including a porous body having fluid permeability characteristics effective to discharge gas from the predetermined gap between said thrust bottom face and said thrust end face at a rate effective for preventing fluctuations between the sleeve and the journal during relative rotation.

2. The fluid bearing according to claim 1,

wherein the magnetic retaining force means includes a permanent magnet disposed along an outer circumferential surface of said sleeve, and means for generating a revolving magnetic field including a stator arranged to surround said permanent magnet across a second predetermined clearance for attracting said permanent magnet to said stator by magnetic force; and

the predetermined gap between said thrust bottom face and said thrust end face is not less than approximately 0.5 mm when there is no relative rotation between the sleeve and journal.

3. The fluid bearing according to claim 1, wherein said sleeve is rotatable and the predetermined clearance between said radial inner peripheral surface and said outer peripheral surface defines an inlet for a fluid adjacent an end portion of said journal opposite said thrust end face.

4. The fluid bearing according to claim 3, wherein the end portion of said sleeve is said porous body.

5. The fluid bearing according to claim 3, wherein the end portion of said sleeve is defined by a peripheral boundary and said porous body is disposed centrally in said end portion radially spaced from the peripheral boundary.

6. The fluid bearing according to claim 3, wherein said journal includes a hollow portion communicating with the end portion thereof, the end portion of said sleeve is closed, and the end portion of said journal includes said porous body.

7. The fluid bearing according to claim 1, wherein said journal is rotatable and the predetermined clearance between said radial inner peripheral surface and said outer peripheral surface defines an inlet for a fluid adjacent an end portion of said journal opposite said thrust end face.

8. The fluid bearing according to claim 7, wherein the end portion of said sleeve includes said porous body.

9. The fluid bearing according to claim 1, wherein the radial outer peripheral surface includes a groove therein for producing dynamic pressure effective to introduce a fluid into the predetermined clearance between said radial inner peripheral surface and said radial outer peripheral surface.

10. The fluid bearing according to claim 9, wherein said sleeve is rotatable and the end portion of said sleeve includes said porous body.

11. The fluid bearing according to claim 9, wherein said sleeve is rotatable, said journal includes a hollow portion communicating with the end portion thereof, the end portion of said sleeve is closed, and the end portion of said journal includes said porous body.

12. The fluid bearing according to claim 9, wherein said journal is rotatable and the end portion of said sleeve includes said porous body.

13. The fluid bearing according to claim 1, wherein said porous body is sintered bronze.

14. The fluid bearing according to claim 1, wherein said porous body is sintered stainless steel.

15. The fluid bearing according to claim 1, wherein said porous body is ceramic.

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(54) STATOR-CONTROLLED MAGNETIC BEARING

(75) Inventors: **H. Ming Chen**, Latham; **James F. Walton, II**, Ballston Lake; **Dennis H. Locke**, Schenectady, all of NY (US)

(73) Assignee: **Mohawk Innovative Technology, Inc.**, Albany, NY (US)

(*) Notice: Under 35 U.S.C. 154(b), the term of this patent shall be extended for 0 days.

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(Under 37 CFR 1.47)

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(52) **U.S. Cl.** .... **310/90**; 310/90.5; 310/68 B; 310/51; 318/615; 318/606; 318/623; 364/565; 364/164

(58) **Field of Search** .... 310/90, 90.5, 68 B, 310/51; 318/615, 128, 623, 649, 606; 364/565, 164, 148, 158

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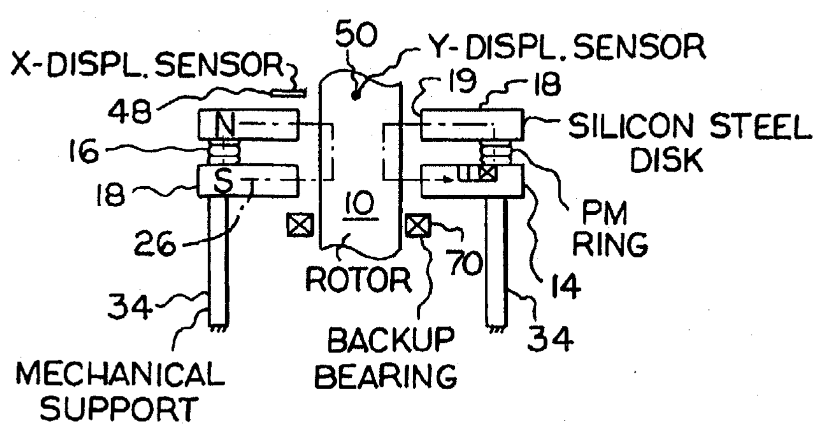
Primary Examiner—Thomas M. Dougherty
Assistant Examiner—Thanh Lam
(74) *Attorney, Agent, or Firm*—James C. Simmons

(57) **ABSTRACT**

A magnetic bearing wherein a stator is magnetically interacted with a rotor and is movable in response to feed-back of rotor position to thereby use the magnetic interaction between the stator and rotor to effect movement of the rotor toward a predetermined rotor position for bearingly controlling the rotor position. The bearing may be a radial or thrust bearing.

20 Claims, 14 Drawing Sheets



which is provided along the radial gap 434 and includes a plurality of, for example, four radially stacked and axially polarized permanent magnet rings 452 on the rotor end which are oriented across the gap from similar magnet rings 454 to magnetically interact therewith. In addition to acting to support the rotor 406, the bearing 450 is also part of the thrust bearing assembly 430, as hereinafter discussed.

The stator portion 422 is received within a cylinder 460 of, for example, stainless steel which is suitably connected to the stator portion 426 by a pair of discs 462 of flexible material such as, for example, thin stainless steel attached at the ends respectively of cylinder 460 and to the portion 426, allowing axial movement of cylinder 460, as illustrated at 464. A disc 466, having a central opening, illustrated at 468, in which the stator portion 422 is received, is suitably attached to the cylinder 460 so that the disc 466 moves axially as the cylinder moves. The magnet rings 454 are suitably mounted on the disc 466 so that magnet rings 454 are movable axially toward and away from magnet rings 452.

A disc 468 is suitably mounted axially centrally on the cylinder 460 and extends radially outwardly therefrom. A radially polarized permanent magnet ring 470 is suitably mounted on the disc 468, generally radially centrally thereof. A pair of electromagnetic coil assemblies 472 are mounted in ferromagnetic material in the form of rings 474 respectively to position the electromagnetic coil assemblies 472 in interactive relationship with the permanent magnet ring 470 with air gaps, illustrated at 476, separating the electromagnetic coil assemblies 472 from the permanent magnet ring 470 respectively. The ferromagnetic rings 474 are attached to the stator portion 426 by suitable mounts, illustrated at 478. Thus, by varying the current supplied to the electromagnetic coil assemblies 472 and the resulting interaction with the permanent magnet ring 470, the disc 468 is movable axially thereby effecting axial movement of the cylinder 460 and the disc 466 on which the permanent magnet rings 454 are mounted. Accordingly, by varying the current to the electromagnet coil assemblies 472, the permanent magnet rings 454 may be moved axially toward and away from the permanent magnet rings 452.

The axial position of the rotor 406 is monitored by a probe, illustrated schematically at 480, which may, for example, be a Hall-effect device. Signals from the probe 480 are continually sent to a current controller circuit 482 via line 483, powered by a suitable power supply 484, which outputs current via lines 486 and 488 to the electromagnetic coil assemblies 472 respectively based on the signals of rotor position to effect movement of the rotor to the predetermined position, using principles commonly known to those of ordinary skill in the art to which this invention pertains. There is an attractive force between each pair of corresponding permanent magnet rings 452 and 454 across the gap 434. When the magnet rings 454 are moved in a direction axially away from magnet rings 452, the lessened or weakened flux or attraction there between will result in a lessened tendency of the rotor to also move in that direction. Thus, as viewed in FIG. 14, when the magnet rings 454 are moved to the right, the magnet rings 452 will be more free to move to the left. Conversely, when the magnet rings 454 are moved to the left, the magnet rings 452 will be urged more to move to the right.

The magnet rings 444 are mounted in a repulsive relation to the corresponding magnet rings 442. When a corresponding pair of magnet rings 442 and 444 are aligned, they are still unstable since an axial force on the rotor will cause the magnet ring 442 to move axially away from the corresponding magnet ring 444. In accordance with the present invention, the magnet rings 442 and 444 are mounted so that the magnet rings 444 on the rotor are shifted a little to the left (away from the radial bearing 450) to a predetermined position relative to the corresponding magnet rings 442 on the stator so that there will be continuously a greater or lesser amount of force acting to pull the rotor to the left (away from the radial bearing 450). The width of gap 434 or the distance between magnet rings 452 and 454 is initially selected to apply an equal force to the right to balance this force acting to pull the rotor to the left. If the rotor is pulled further to the left (past the predetermined position), this will be sensed by probe 480 which will so signal the current controller which will in turn vary the current to the electromagnetic coil assemblies 472 to interact magnetically with the permanent magnet 468 to effect movement of the magnet rings 454 to the left (toward magnet rings 452) thus increasing the attractive force there between to effect movement of the rotor back to the right to the predetermined position. If the rotor, when pulled to the right is pulled past the predetermined position, this will also be sensed by probe 480 which will so signal the current controller which will in turn vary the current to the electromagnetic coil assemblies 472 to interact magnetically with the permanent magnet 468 to effect movement of the magnet rings 454 to the right (away from magnet rings 452) thus decreasing the attractive force there between to allow movement of the rotor back to the left to the predetermined position. Thus, the rotor position is continuously monitored and the current to the electromagnetic coil assemblies 472 continuously varied as necessary to continually effect movement of the rotor to the predetermined axial position.

In order to contain the flow of fluid within the gaps 432, 434, and 436 so that it does not flow out into other spaces where it might stagnate, a suitable fluid impermeable flexible sheet 490 is suitably attached to suitably extend between disc 466 and the stator portion containing the motor stator coils 418, and another suitable fluid impermeable flexible sheet 492 is suitably attached to suitably extend between disc 466 and the stator portion 426.

Thus, there is provided in accordance with the present invention a stator-controlled magnetic bearing wherein the stator is moved in response to feed-back of rotor position to effect movement of the rotor toward a predetermined position. The bearing may be a journal bearing which has a laterally-movable stator without protruding poles to face the rotor. The stator utilizes a permanent magnet ring so that the annular distribution of radial magnetic flux in the air gaps may be uniform circumferentially whereby there are little or no eddy current or magnetic hysteresis losses. Since the magnetic bearing is actively controlled, its stiffness and damping properties may be electronically manipulated thus making it ideal for supporting high speed rotors such as those of momentum and energy storage flywheels. The bearing may alternatively be a thrust bearing.

It should be understood that, while the invention has been described in detail herein, the invention can be embodied otherwise without departing from the principles thereof, and such other embodiments are meant to come within the scope of the present invention as claimed by the appended claims.

What is claimed is:

1. A bearing for a rotor comprising a stator, means for magnetically interacting said stator with the rotor, and means responsive to feed-back of a rotor position for moving said stator relative to the rotor position to thereby use changes in forces of the magnetic interaction between said stator and the rotor resulting from movements of the stator

relative to the rotor position to effect movement of the rotor toward a predetermined rotor position for bearingly controlling position of the rotor.

2. A bearing according to claim **1** wherein said magnetically interacting means comprises a magnet in a shape of a ring disposed on one of said rotor and said stator and extending circumferentially of said rotor.

3. A bearing according to claim **1** further comprising means for inputting to said stator moving means measurements of difference in flux density at diametrically opposed sides of the rotor.

4. A bearing according to claim **1** further comprising means for electronically dampening vibrations of said stator.

5. A bearing according to claim **1** wherein said stator moving means comprises means for applying magnetic fields to said stator for moving thereof, the bearing further comprising means for isolating the magnetic fields of said stator moving means from magnetic fields of said means for magnetically interacting said stator with the rotor.

6. A bearing according to claim **1** wherein the bearing is a journal bearing, the bearing further comprising means defining circumferentially extending grooves in the rotor and said stator which are axially alignable in response to changes in reluctance at the grooves for bearingly maintaining axial position of the rotor.

7. A bearing according to claim **1** wherein the rotor is tubular, and said stator is received within the rotor.

8. A bearing according to claim **1** further comprising means for inputting to said stator moving means signals representing dynamic unbalance forces on the rotor for outputting signals for movement of the stator which cancel the dynamic unbalance forces on the rotor for balancing thereof.

9. A bearing according to claim **1** wherein said magnetically interacting means comprises a magnet and means for disposing said magnet in position for effecting magnetic interaction between said stator and the rotor without being attached to either the rotor or said stator.

10. A bearing according to claim **9** wherein said magnet is an electromagnet.

11. A bearing according to claim **9** wherein said magnet is in a shape of a ring and extends circumferentially of said rotor.

12. A bearing according to claim **1** wherein the bearing is a journal bearing.

13. A bearing according to claim **1** wherein the bearing is a thrust bearing.

14. A bearing according to claim **1** wherein the bearing has a gap width which is at least about 0.03 inch.

15. A bearing according to claim **1** further comprising means for dampening stator vibrations.

16. A bearing for a rotor comprising a stator which circumscribes the rotor, means for magnetically interacting said stator with the rotor, and means responsive to feed-back of a rotor radial position for moving said stator radially relative to the rotor radial position to thereby use chances in forces of the magnetic interaction between said stator and the rotor resulting from movements radially of the stator relative to the rotor radial position to effect movement of the rotor radially toward a predetermined rotor radial position.

17. A method for bearingly controlling position of a rotor comprising magnetically interacting a stator with the rotor and moving the stator relative to a rotor position in response to feed-back of the rotor position to thereby use changes in forces of the magnetic interaction between the stator and the rotor resulting from movements of the stator relative to the rotor position to effect movement of the rotor toward a predetermined rotor position.

18. A method according to claim **17** wherein the step of moving the stator comprises moving the stator radially in response to feed-back of the rotor radial position to effect movement of the rotor toward a predetermined rotor radial position.

19. A method according to claim **17** wherein the step of moving the stator comprises moving the stator axially in response to feed-back of the rotor axial position to effect movement of the rotor toward a predetermined rotor axial position.

20. A method according to claim **17** further comprising electronically dampening stator vibrations.

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